1. A 240-V, 20-kVA, 0.8-PF-lagging, 60-Hz, four-pole, Y-connected synchronous generator has a synchronous reactance of 0.2 \( \Omega \). This generator is operating in parallel with a large power system (infinite bus).

(a) What are the maximum, minimum, and average speed of this generator in RPM?

(b) What is the magnitude of \( E_A \) at rated conditions?

(c) If the field current is constant, what is the maximum **torque** possible out of this generator?

Solution:

(a) The synchronous generator runs at synchronous speed under all conditions.

\[
\begin{align*}
n_{\text{max}} &= n_{\text{min}} = n_{\text{ave}} = n_{\text{syn}} = \frac{120f_c}{P} = \frac{120(60)}{4} = 1800\text{RPM}
\end{align*}
\]

(b) At rated conditions:

\[
\begin{align*}
S_{\text{load}, \phi} &= S_{\text{rated}, \phi} = \frac{20,000}{3} \angle \cos^{-1}(0.8) = 6667 \angle 36.87^\circ \text{VA} \\
V_{T, \phi} &= V_{\text{rated}, \phi} = \frac{240\angle 0}{\sqrt{3}} = 138.56 \angle 0^\circ \text{V} \\
I_A &= \left( \frac{S_{\text{load}, \phi}}{V_{T, \phi}} \right)^* = \left( \frac{6667 \angle 36.87^\circ}{138.56 \angle 0^\circ} \right)^* = 48.1 \angle -36.87^\circ \text{A} \\
E_{A, \phi} &= V_{T, \phi} + I_A (jX_S) = 138.56 \angle 0^\circ + 48.1 \angle -36.87^\circ (j0.2) = 144.54 \angle 3.05^\circ \text{V}
\end{align*}
\]

So the magnitude of \( E_A \) at rated conditions is \( |E_A| = \sqrt{3}|E_{A, \phi}| = \sqrt{3}(144.54) = 250.36 \text{V} \)

(c) The active power supplied by the generator to the power system is:

\[
P = \frac{E_AV_T}{X_S} \sin \delta \quad \text{(Line-to-line voltages)}
\]

The maximum possible active power out of this generator is:

\[
P_{\text{max}} = \frac{E_AV_T}{X_S} = \frac{(250.36)(240)}{0.2} = 300\text{kW}
\]

The mechanic speed of this generator is:

\[
\omega_m = n_{\text{sync}} \frac{2\pi}{60} = 1800 \frac{2\pi}{60} = 188.5 \text{rad/s} \quad \text{(Or } \omega_m = \frac{2}{P} \omega_e = \frac{2}{4} 2\pi(60) = 188.5 \text{ rad/s} \text{)}
\]

So the maximum possible torque out of this generator is:

\[
T_{\text{max}} = \frac{P_{\text{max}}}{\omega_m} = \frac{300 \times 10^3}{188.5} = 1593.8 \text{Nm}
\]